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THE DESIGN AND DEVELOPMENT OF TWO-FAILURE TOLERANT MECHANISMS FOR THE SPACEBORNE IMAGING RADAR (SIR-B) ANTENNA

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ABSTRACT

This paper describes the performance requirements, design constraints, and design qualification status of the mechanisms necessary to restrain, deploy, and stow the SIR-B antenna experiment on the Shuttle Orbiter.

INTRODUCTION

The SIR-B antenna is a flat array that must mount stowed into a standard European Space Agency Shuttle pallet within a small envelope so that the pallet may be shared with other experiment(s). For this purpose, the antenna array was divided into three sections: center, aft, and forward. The center section remains attached to a pallet mounting truss, the fore and aft sections rotate on hinges perpendicular to the Shuttle centerline to nest atop the center section. The forward is the inner leaf and the aft is the outer leaf. Upon command, the mechanism must remove the Launch and Landing Restraint System (L/LRS), deploy the antenna leaves to a flat position, and initiate antenna tilt on an axis parallel to the centerline of the Shuttle to any command position betwen 15° and 60° elevation. After experiment conclusion, or at any time during the mission, the mechanism must stow the antenna and latch it ready for re-entry. (See Figure 1 and Figure 2.)

DESIGN CONSTRAINTS

Safety Considerations

Because the antenna protrudes beyond the Shuttle payload bay door envelope after it is deployed and tilted to the maximum angle of travel, safety requirements may be met only by jettisoning the antenna array or by using two failure tolerant mechanisms to ensure safe stowage and latching into landing configuration. We have selected the latter approach. See Figure 3.

Loads

The stowed antenna is exposed to the launch and landing loads encountered in the Shuttle cargo bay.

Performance

The deployed antenna array must deploy and remain flat within 6.35 mm (0.25 inch).

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Schedule

Existing mechanisms were to be used where possible to reduce design and development time.

Power

28 Vdc power available.
115 Vac 400-Hz power available (manual controlled console only).

Sixteen pyro-initiator circuits available (eight pyro devices possible; manual console only.) Restricted to NASA Standard Initiators (NSI-1) only.

Environment

The antenna mechanism must be capable of operation in hard vacuum at -34.4° to +71.1°C (-30° to +160°F.) Multilayer insulation may be used as required to maintain the mechanism temperature within those limits.

DESIGN SUMMARY

The basic antenna array is made of eight subarrays or panels arranged into three sections. All panels are supported by tubular aluminum structure. The center section is backed by a rigid triangular truss and the aft and forward sections are supported by a flat frame. The antenna array is stowed into approximately one third of its deployed length (from 10.74 to 3.99 m) (423 to 157 inches). The center section remains stationary, the forward (inner) section folds into it, and the aft (outer) section folds over the other two. A locking latch between the center and outer leaves is provided to obtain a solid package. See Figures 1 and 2.

To mount the antenna array into the Shuttle accommodation pallet, a rigid tubular frame (pallet truss) is used that also serves to support the two redundant electrical control boxes.

The antenna pointing requirement is accomplished through a tilt hinge, located between the pallet truss and the antenna array, the axis of which is parallel to the antenna array longitudinal axis. The hinge moves between solid stops and is stowed solid to the pallet truss and locked by a latch for launch and landing. See Figure 3.

The antenna panels are bolted onto the tubular structure by a system of flat fittings with holes to fit the various tube diameters. The fittings have either round or elliptical holes to accommodate panel differential expansion relative to the structure.

From Mission Profile

- The antenna must be stowed and latched during Shuttle launch.
- The latches are retracted and held.
- The antenna array to be deployed flat within 6.35 mm (0.25 in).
- The antenna is pointed (tilted) to a (commanded) angle and must hold within 0.5°.

From Safety (Constraints)

- Double failure tolerant mechanisms to stow antenna within Shuttle door envelope.
- Double failure tolerant mechanisms to latch for landing.
- Single failure tolerant bearings throughout the system.

From Ground Testing

- Actuator torque 11.30 Nm (100 in-lb) minimum.
- Structual rigidity required at 1 g for ground functional tests.

MECHANISM DESCRIPTION

Drives

The aft and forward folding hinges are driven by dc rotary dual drive actuators (DDA) in both deploy and stow directions. In the event of total dc actuator failure (double failure), or two dc power failures, the DDA is a pyro pin puller, and a preloaded viscous dampened actuator (VDA) is released by another pin puller. The VDA will rotate to contact a leaf hinge cross pin and mechanically power the leaf back to stowed position. This third redundant option is manually controlled from the Shuttle cabin through a separate pyro firing console. See Figures 4 and 5.

The tilt hinge is similar to the folding hinges except that there is a negator spring, constantly engaged in the stow direction, which provides a backlash cancelling preload to achieve accurate antenna pointing. There is also a rotary potentiometer for tilt position feedback. See Figure 6.

Launch/Landing Restraint System (L/LRS)

The fore and aft leaves are firmly held to the center leaf by stops reacting against the hinges, and latched by a mechanical claw mounted at the center leaf structure which captures a roller at the forward leaf, thus trapping both leaves against the center leaf.

The entire antenna array is also held to the pallet truss by a similar mechanical claw and roller combination

MECHANISM DETAILS

- Dual Drive Actuator (DDA)--Originally developed by the Jet Propulsion Laboratory (JPL) for their Galileo Antenna Deployment. [Ref: 16th Aerospace Mechanisms Symposium, NASA Conference Publication 2221, May 13-14, 1984.] The DDA basically consists of two dc motors driving independently through redundant differential harmonic drives.

  Because of inertial loading of the antenna structure, the DDA output rpm needed to be reduced 10:1 by modifying the harmonic drive gear ratio which increased the output torque. An output torque limiting clutch has been added to the DDA.

- Viscous Dampened Actuator (VDA)--A rotary vane within a matching cylinder for a 186° minimum rotation is dampened by 100,000 centistrokes silicone fluid. Rotary power is provided by two constant torque (negator) spring packs on two cylindrical guides at each end of the rotor. There is a thermal compensator/reservoir device Belleville spring loaded and positioned at approximately midstroke during room temperature filling of the VDA chamber.

  All three VDA's are preloaded before flight and retained by independent pyrotechnically initiated pin pullers.

  A cross pin, which is located at the hinge pin end and closest to the VDA, rotates within a scroll chamber formed by one of the VDA spring guides. As the pyro pin is retracted and the VDA spring guide rotates, the flat at the scroll end contacts the cross pin and transmits torque to the hinge pin. There is never contact between the VDA and the antenna drive mechanism until the pyro pin is pulled.

- Launch/Landing Restraint System (L/LRS)--This consists of a roller and an electric motor actuated claw that engages the roller. The roller is supported by a pin through a bracket bolted to either the aft leaf or antenna truss frame. This claw is part of a latch mechanism in a housing bolted to either the antenna center truss or the pallet truss frame.

  The claw pivots through an arc of 42° pushed by a carriage driven by a ball screw nut. The ball screw is rotated by an actuator with two motors on the same shaft. See Figure 7.

  Because of the two fault tolerant requirements, as a backup to this main claw for the (landing) stow function only, there is a secondary claw deployed by a pyro pin puller. After deployment the secondary claw is held in place by a ratchet and pawl device. The secondary roller is located by the same pin and bracket arrangement used for the primary claw. See Figure 8.

- Bearings--All critical bearings are single failure tolerant.

  - The main hinge bearings are aluminum cylinders with a solid lubricant at the I.D. and O.D. The lubricant is a polyester resin interdispersed with polytetraflurotethylene (PTFE) in flock or powder form. (Figure 9).

  - The latch assembly ball screw end bearings also have polyester/ PTFE lube and run inside bearium metal sleeves.

  - The main hinge thrust bearings are large outer diameter, aluminum washers lubricated on both sides with polyester/PTFE lube.

  - The latch rollers are coated, outer diameter and inner diameter, with molybdenum disulfide solid film lubricant.

  - The latch main claw actuator has leaded bronze dual rotating surface sleeve bearings at the output shaft.

DEVELOPMENT PROBLEMS AND SOLUTIONS

Ball Screw

The latch assembly ball screw mechanism was originally designed to contain Nomex felt wipers bonded to the ice scraper. The wiper method of retention was found unsatisfactory because during engineering verification tests, a wiper came off and was trapped in the ball nut. The wiper was eliminated and the ball screws were lubricated and assembled minus the wipers. The latch assembly contamination barrier surrounding the mechanism was improved to minimize the risk of contaminants entering the area. There were no difficulties with an open (no barrier) latch assembly used during the hinge assembly specimen vibration and thermal vacuum tests.

Hinges

Initially all antenna trusses were to be assembled and riveted, then the hinge press fit, matched drilled, and held with bolts. Because of tolerance requirements, the hinges needed to be mated with an assembly tool (continuous bar), the truss corner fittings matched to the hinges and then the truss work connected and riveted. This method of assembly resulted in satisfactory alignment.

Lubrication

Tight fits between fittings and outer diameter tubing caused surface scratches in some tubes. This problem disappeared when the tubes were lubricated with a film of BASD grease 37951M. All excess grease was wiped off after assembly.

Thrust Washers/Shims

To compensate for thermal expansion/contraction, the fold leaf hinges on the VDA side require a gap of 0.61 ±0.05 mm (0.024 ±0.002 in) which is controlled with solid aluminum shims. During assembly with the antenna array in the vertical position (hinge centerline perpendicular to floor), this structure deflected to the point that the shims were in bearing (thrust loads) and some wear and metal shavings appeared. The problem was solved by measuring the gap to be compensated and machining custom spacers (to obtain the desired 0.61 ±0.05-mm gap) from spare thrust washers. There was no difficulty in machining polyester/PTFE material to obtain a load sharing thrust bearing system for 1 g assembly.

QUALIFICATION STATUS

The dual drive actuators have been designed, manufactured, and tested. Engineering verification testing and qualification included vibration tests. All flight hardware is now installed.

The viscous dampened actuators have been designed, manufactured, and filled with silicone fluid. Acceptance and engineering verification tests at minimum and maximum temperature in vacuum have been completed.

Performance simulation tests were conducted with a test specimen of a latched tilt hinge in the vertical position in a thermal vacuum chamber. These tests were followed by random vibration tests.

CONCLUSIONS

A different approach to two failure tolerant mechanisms has resulted in an experiment that does not require jettison capabilities to comply with the NASA safety requirements applicable to "Payloads using the Space Transportation System." [Ref: NASA HNB 1700.7A.]

All development problems encountered so far have been corrected. The hinge assembly specimen tests verified the bearings and latch assembly performance at extreme temperature in vacuum and at random vibration.

ACKNOWLEDGEMENT

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Table 1
Limit Loads and Motion Requirements

Component	Limit Load or Torque	Motion Requirements	Actuator/Output
Tilt hinge	Calculated mission max torque 3.96 N.m (35 in.-lbs.)	Max. rotation 15° to 60° antenna pos. at 2°/sec max from 60° max, return to 15° position back-up mode	DDA (loc. cit.)/ output 14.71 N.m (130 in.-lbs.) 0.15 rpm (0.9°/sec) VDA (loc. cit.)/ output 10.73 N.m (95 in.-lbs.) 0.0095 rpm (0.57°/sec at -34.4°C at -30°F)
Fold hinge	Calculated mission max torque [illegible]6 N.m (21.2 in.-lbs.) A[illegible] test at vert. position 3.[illegible]0 N.m (30 in.-lbs.)	Normal max rotation 180° Back-up max rotation 180°	DDA/see above VDA/see above
Latch (main claw)	Separation load 6547.4N (1472 LBf) Torque at actuator 2.877 N.m (25.47 in.-lbs.) Running Loads 0.565 N.m (5 in.-lbs. max)	Hold at limit claw motion	General Design Inc. actuator model 9280/ Actuator holding torque de-energized 5.649 N.m (50 in.-lbs.) Actuator running torque 2.25 N.m (20 in.-lbs.) actuator max torque 5.649-7.910 N.m (50-70 in.-lbs.)
Latch Secondary claw pyro initiated	Inertial load of 0.467 Kg (1.03 lbs) Ratchet load of 51.15N (11.5 LBf) Remaining load of 444.8N (100LBf) after initial 0.013m (0.50 inch) stroke	17.8mm (0.70 inch) linear motion for a 42° claw rotation	BASD Spec 74232-501 (linear) pin puller/ Engineering unit successfully tested at required conditions

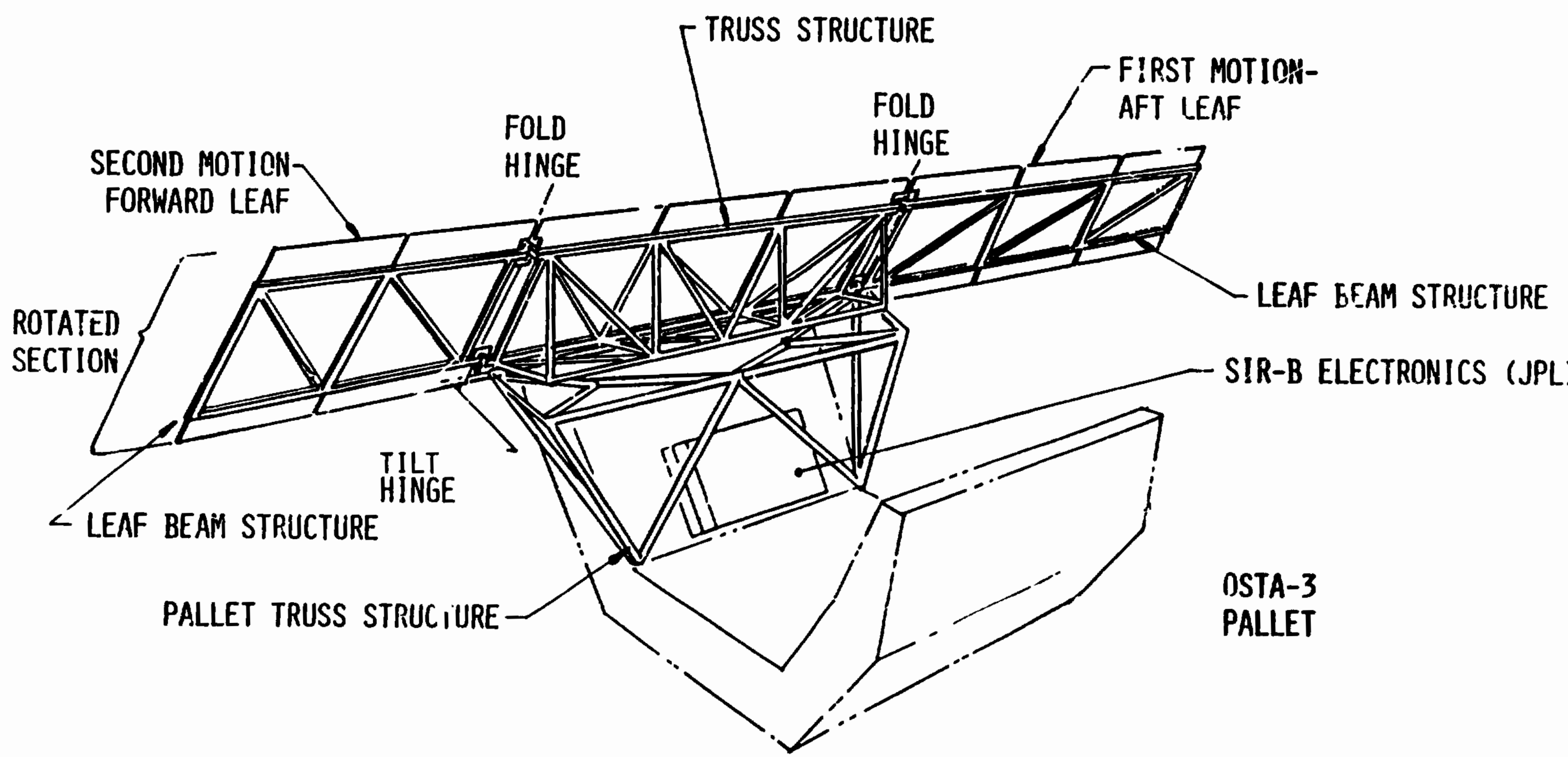

Figure 1. SIR-B On-Orbit Configuration

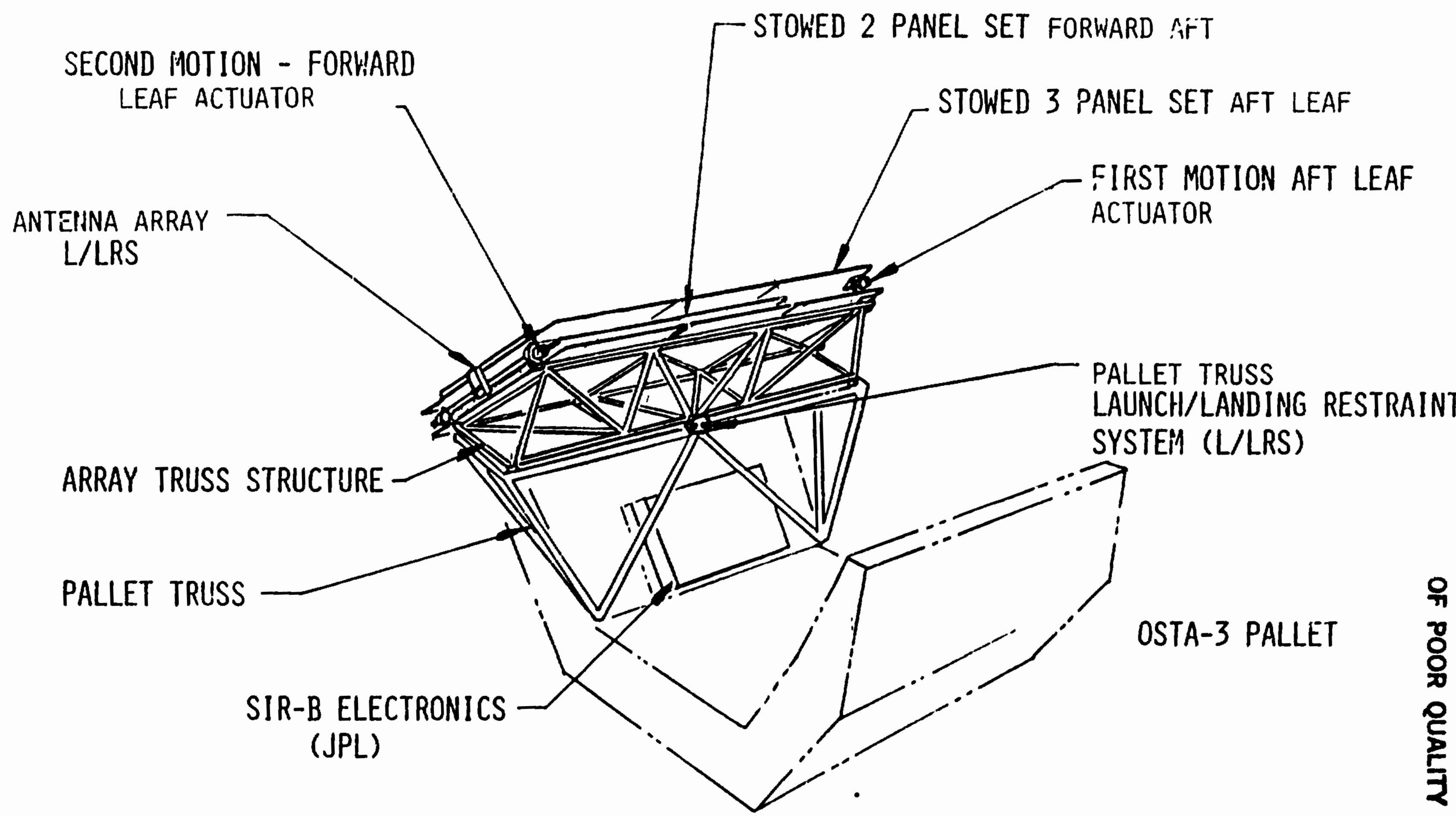

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Figure 2. SIR-B Launch/Landing Configuration

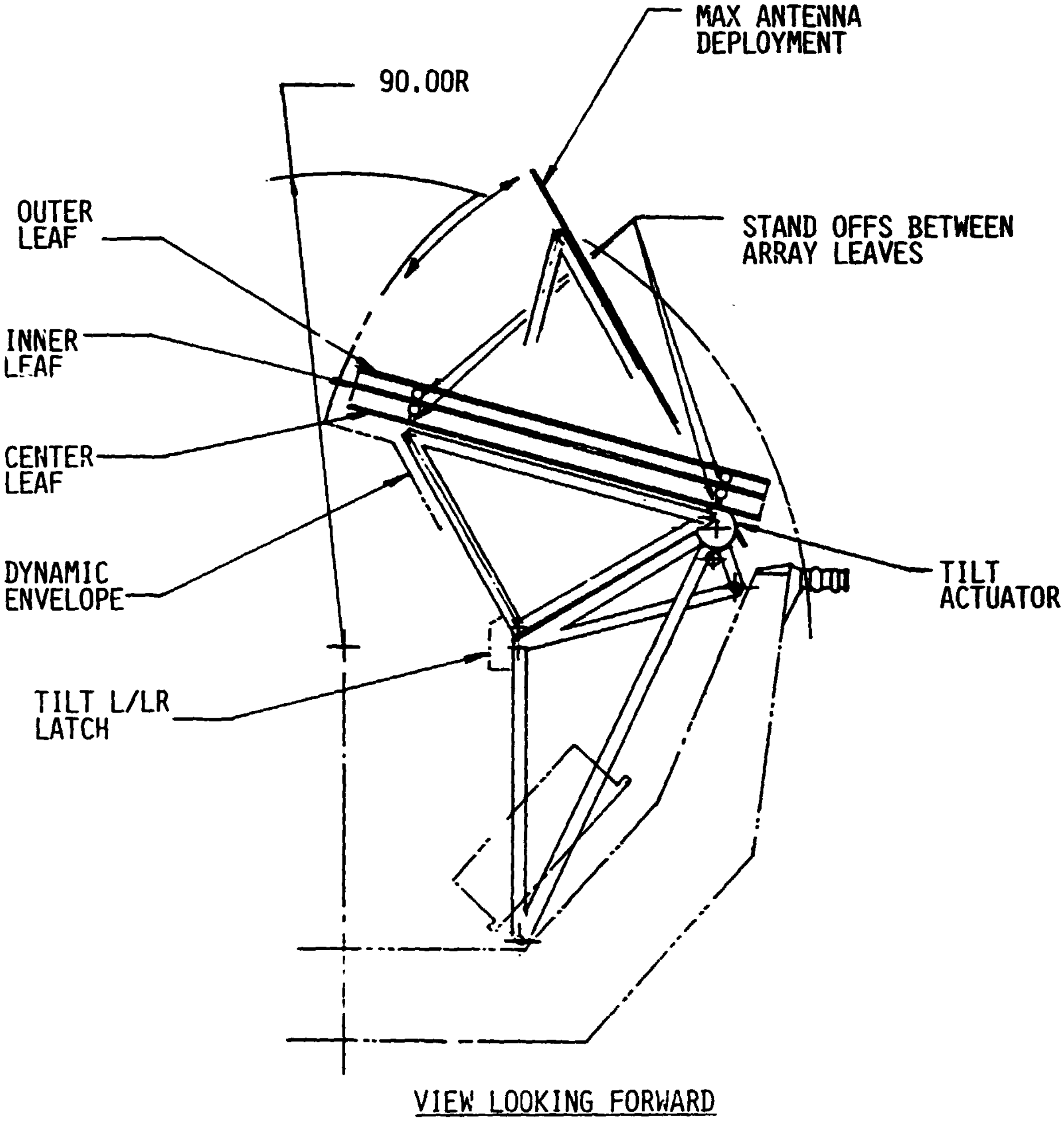

Figure 3. SIR-B Launch/Landing Configuration

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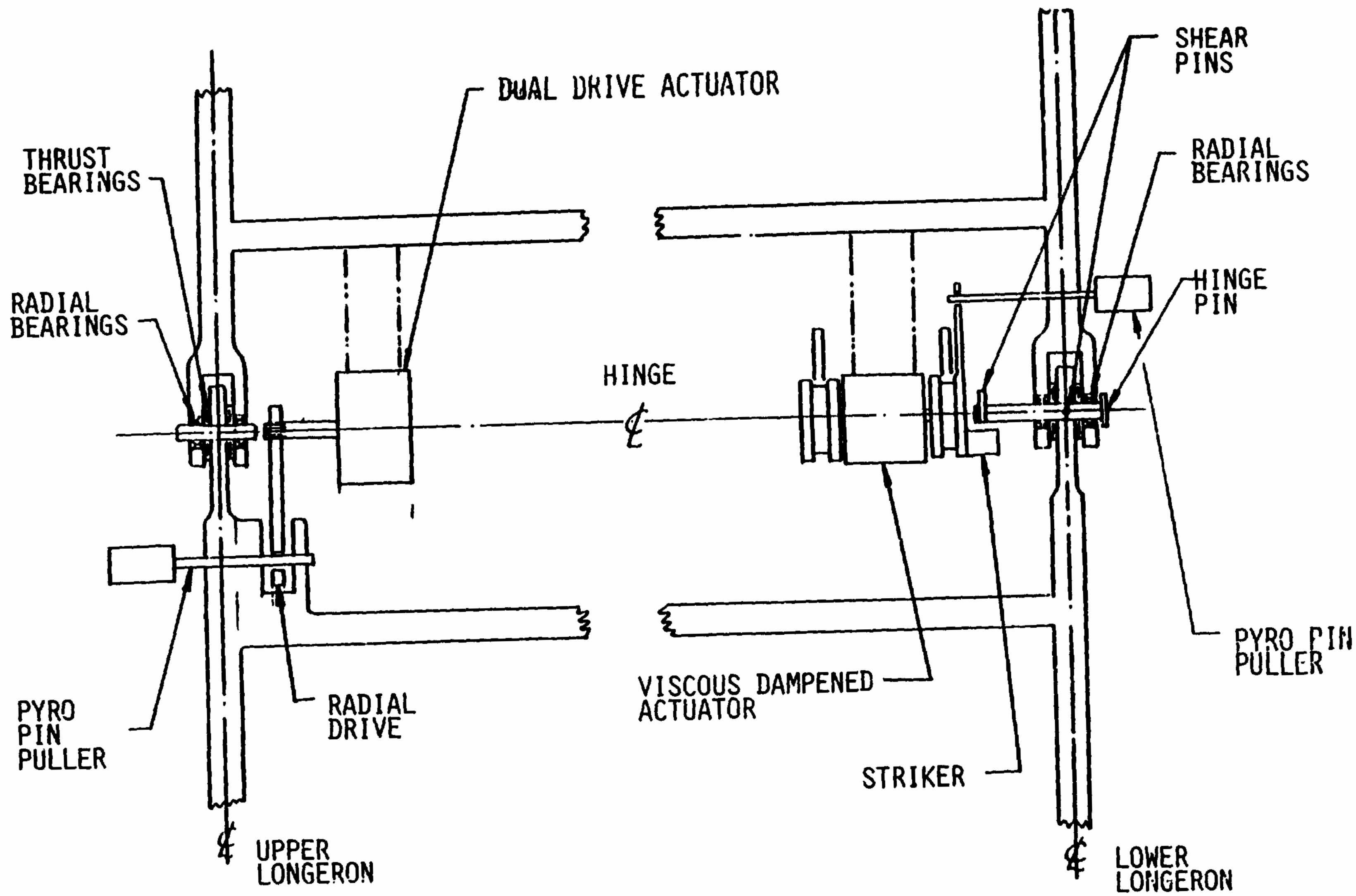

Figure 4. System Functional Diagram (Leaves)

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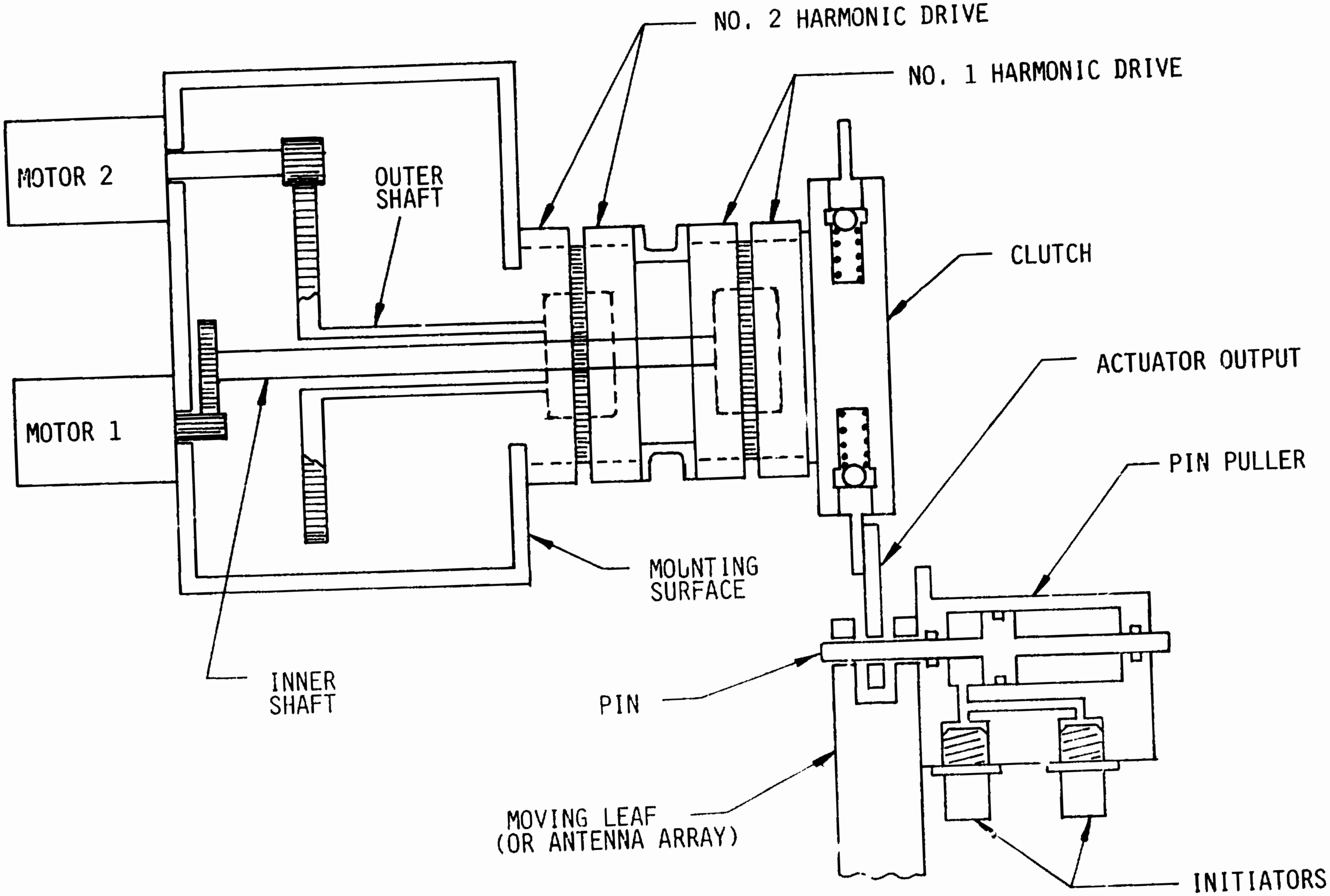

Figure 5. Dual Drive Actuator and Pyro Disconnect Schematic Diagram

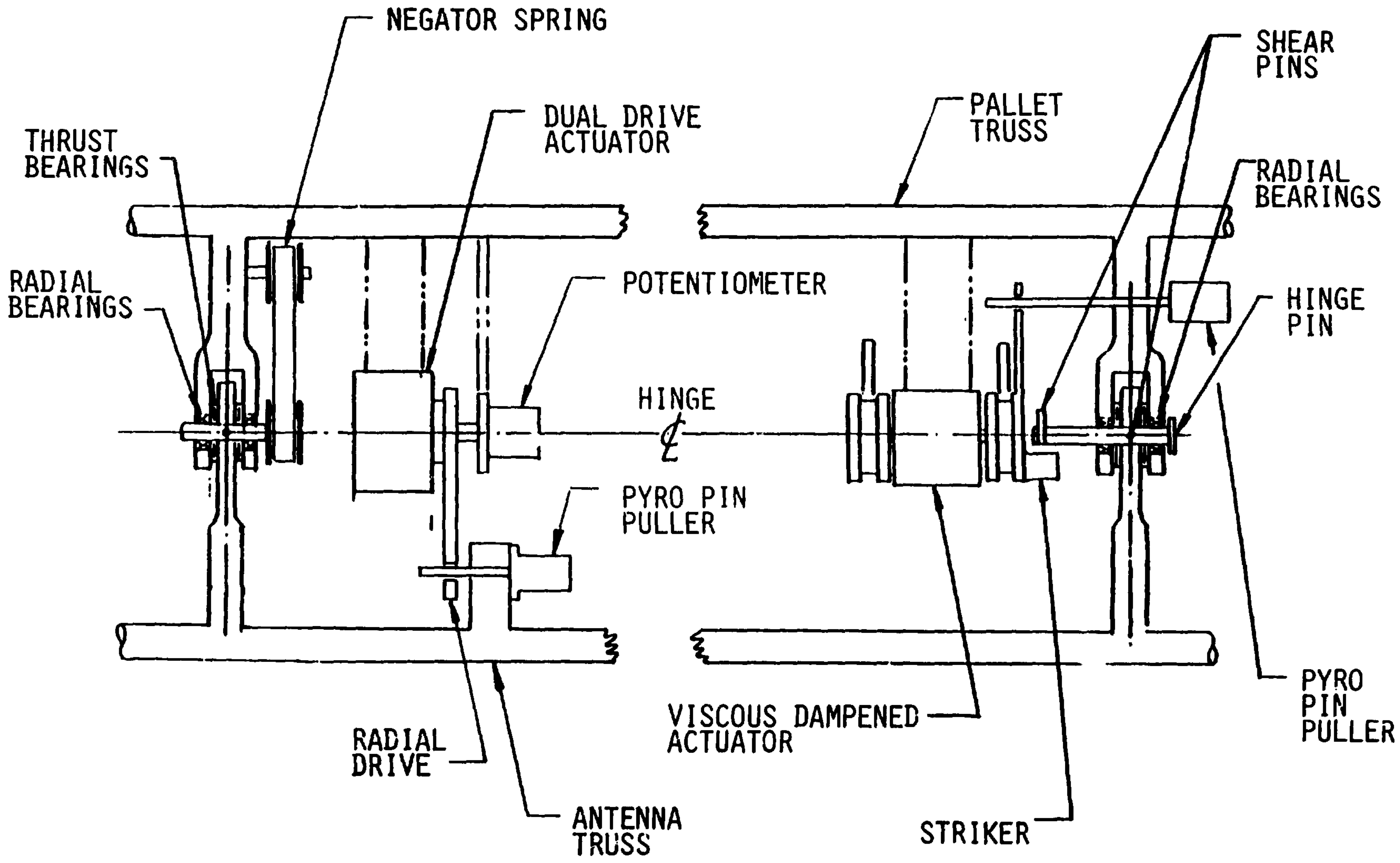

Figure 6. System Functional Diagram (Tilt Hinge)

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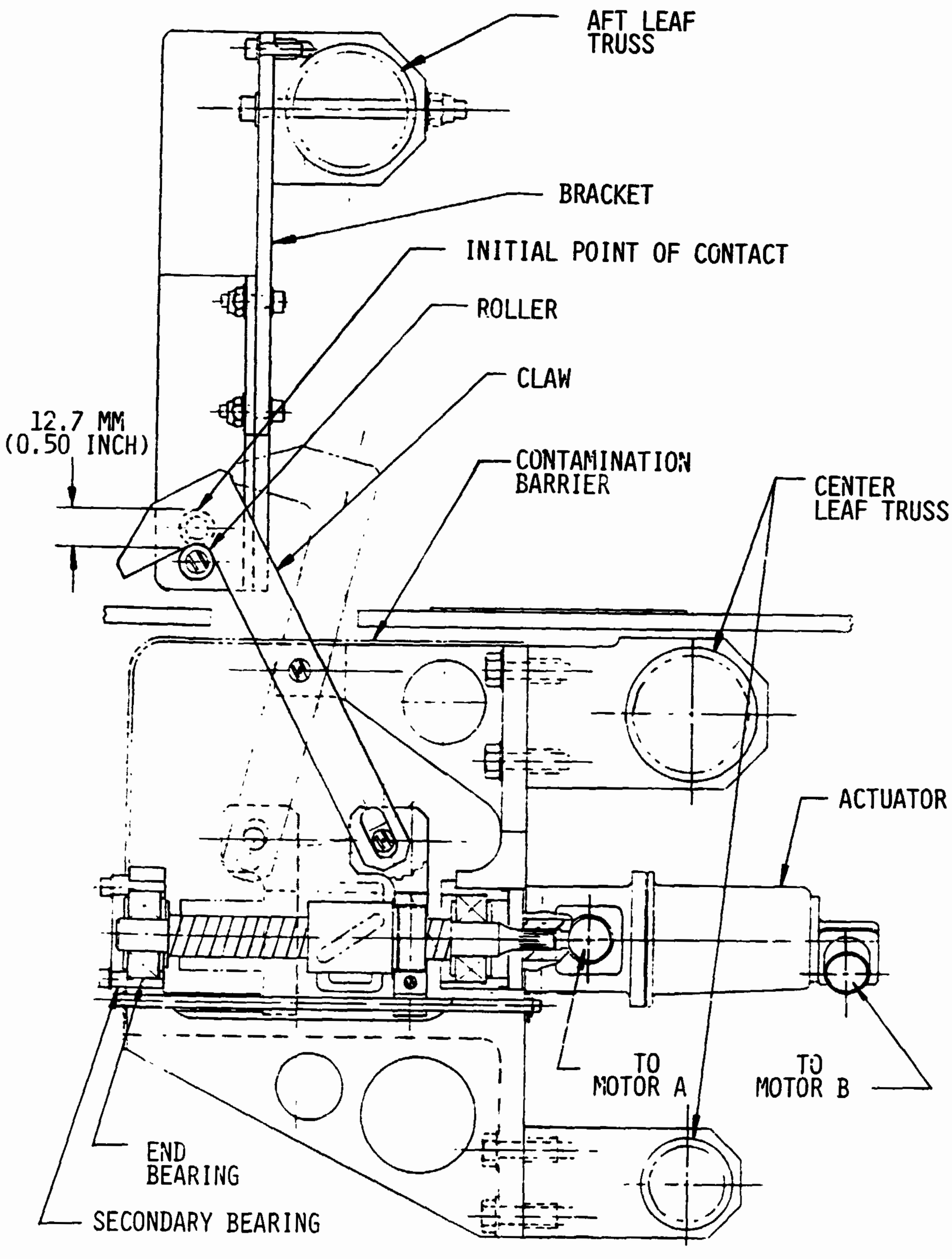

Figure 7. Launch/Landing Restraint System

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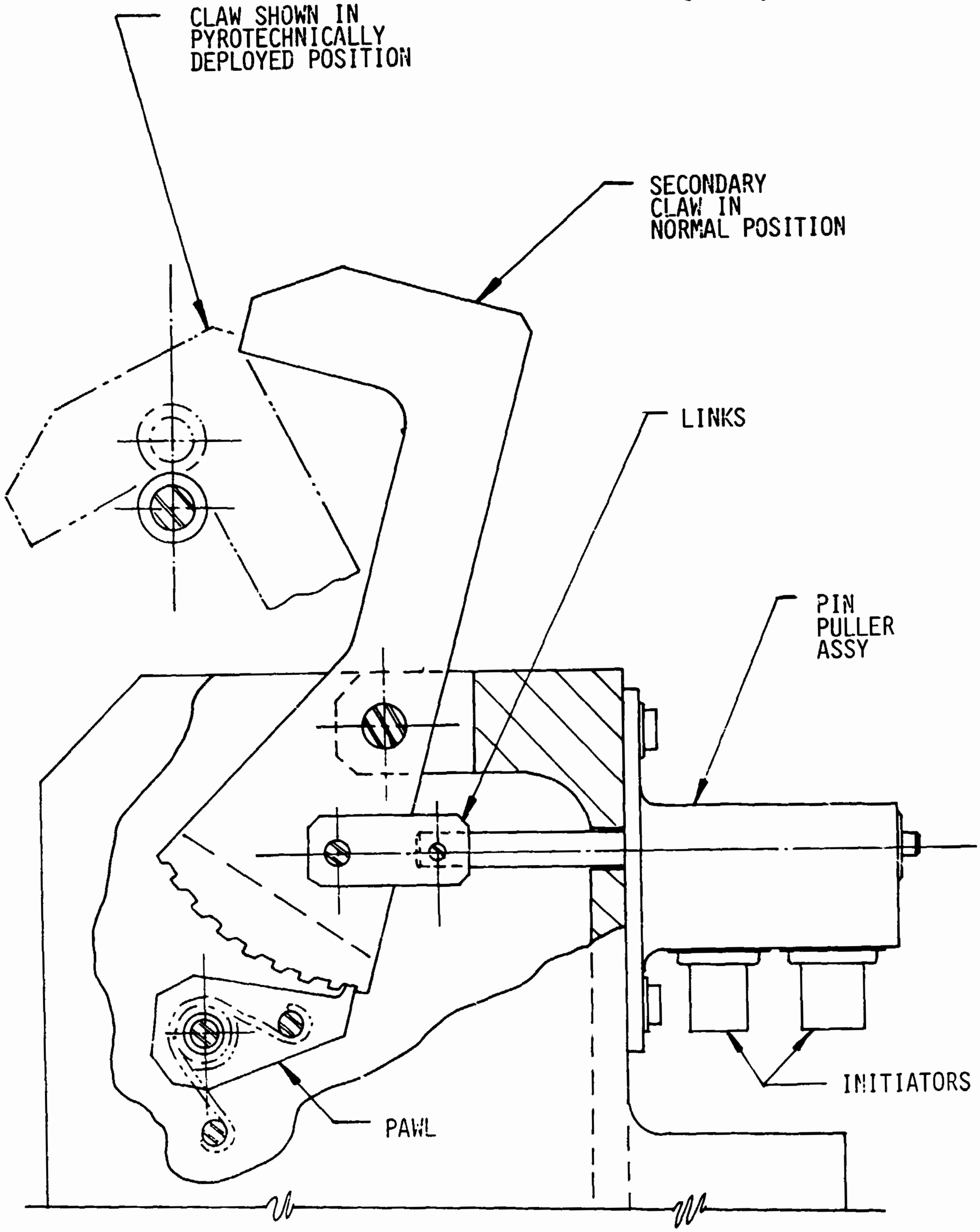

Figure 8. Secondary/L/LR Latch

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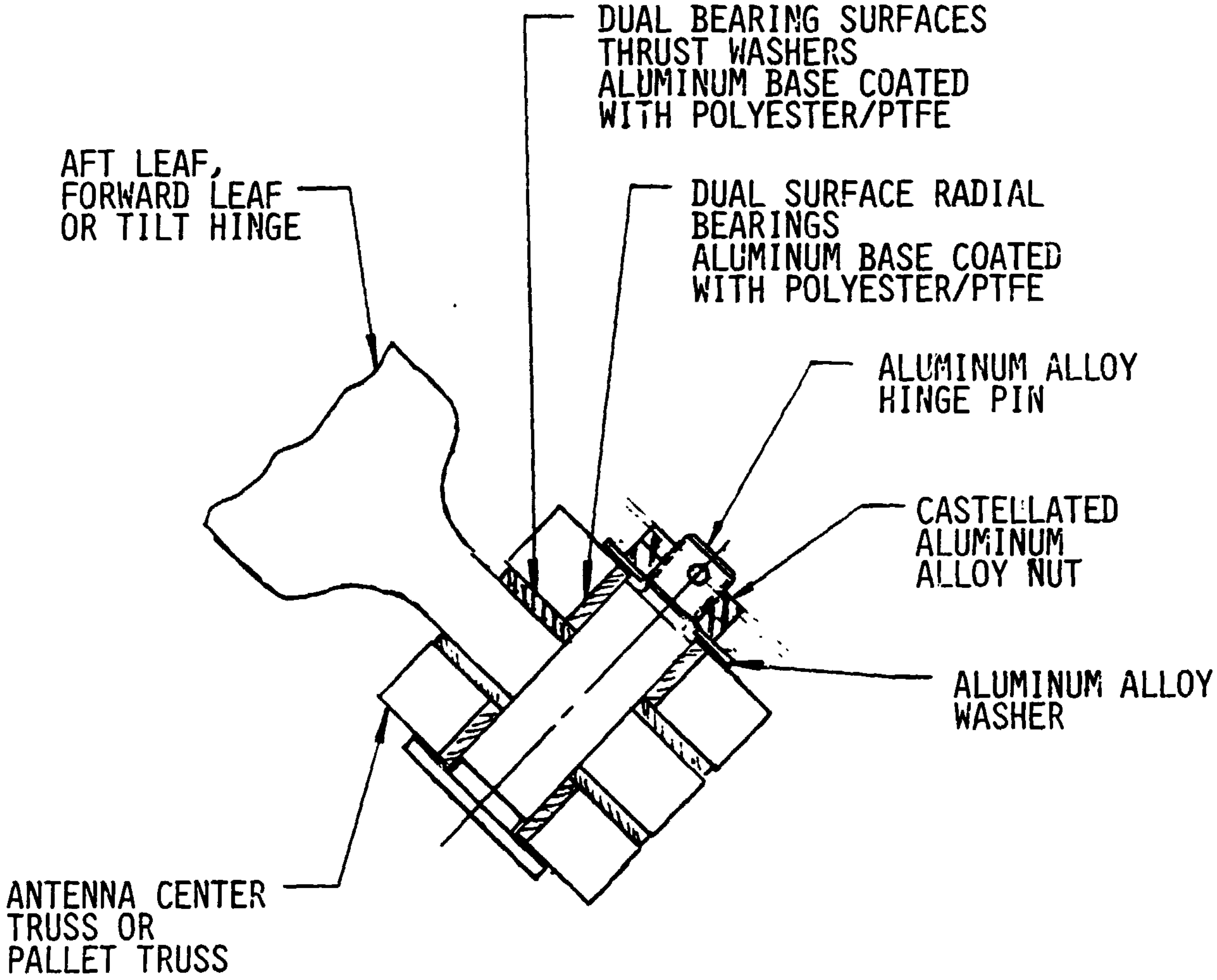

Figure 9. Typical Thrust/Radial Load Carrying Hinge

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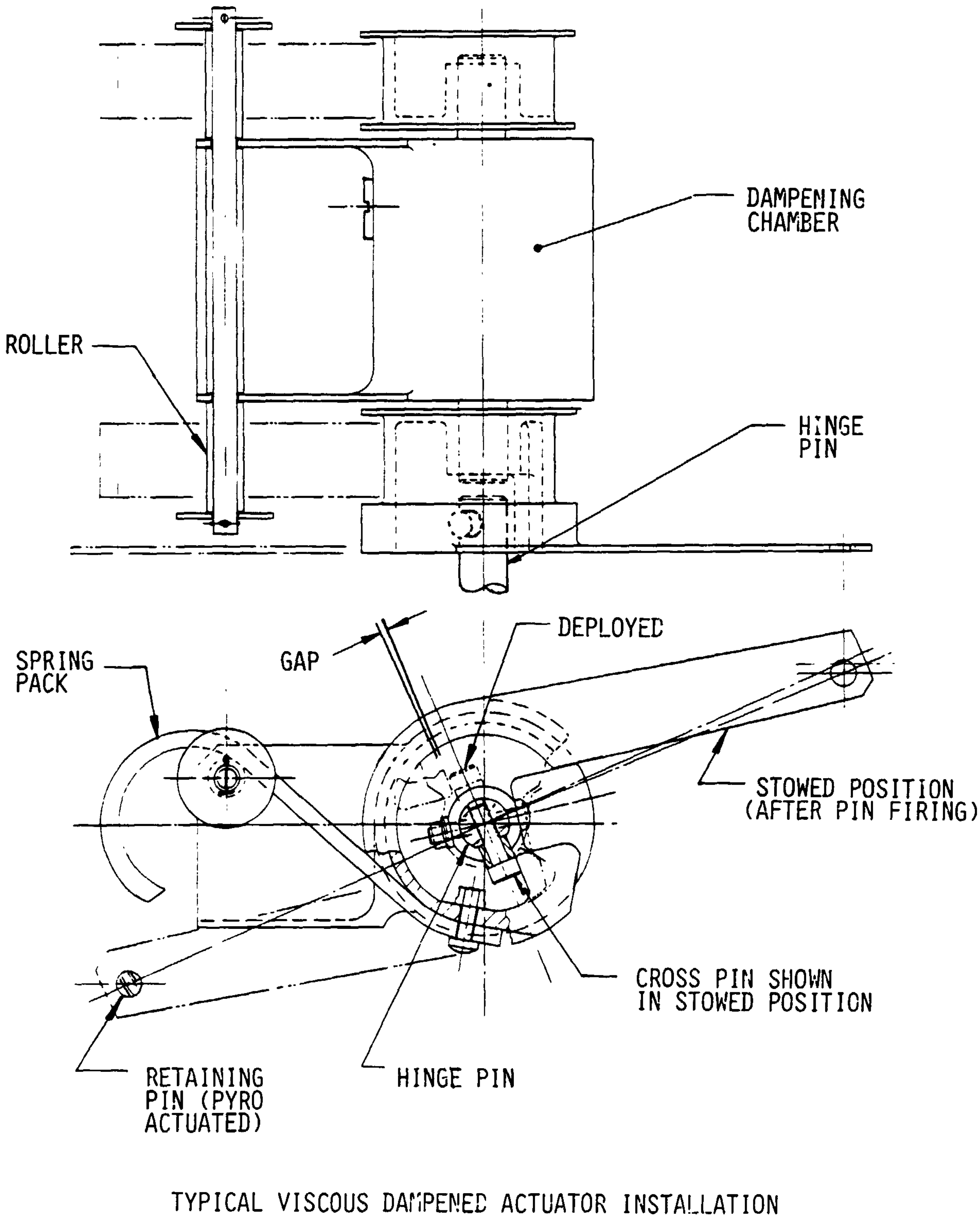

Figure 10. Typical Viscous Dampened Actuator Installation

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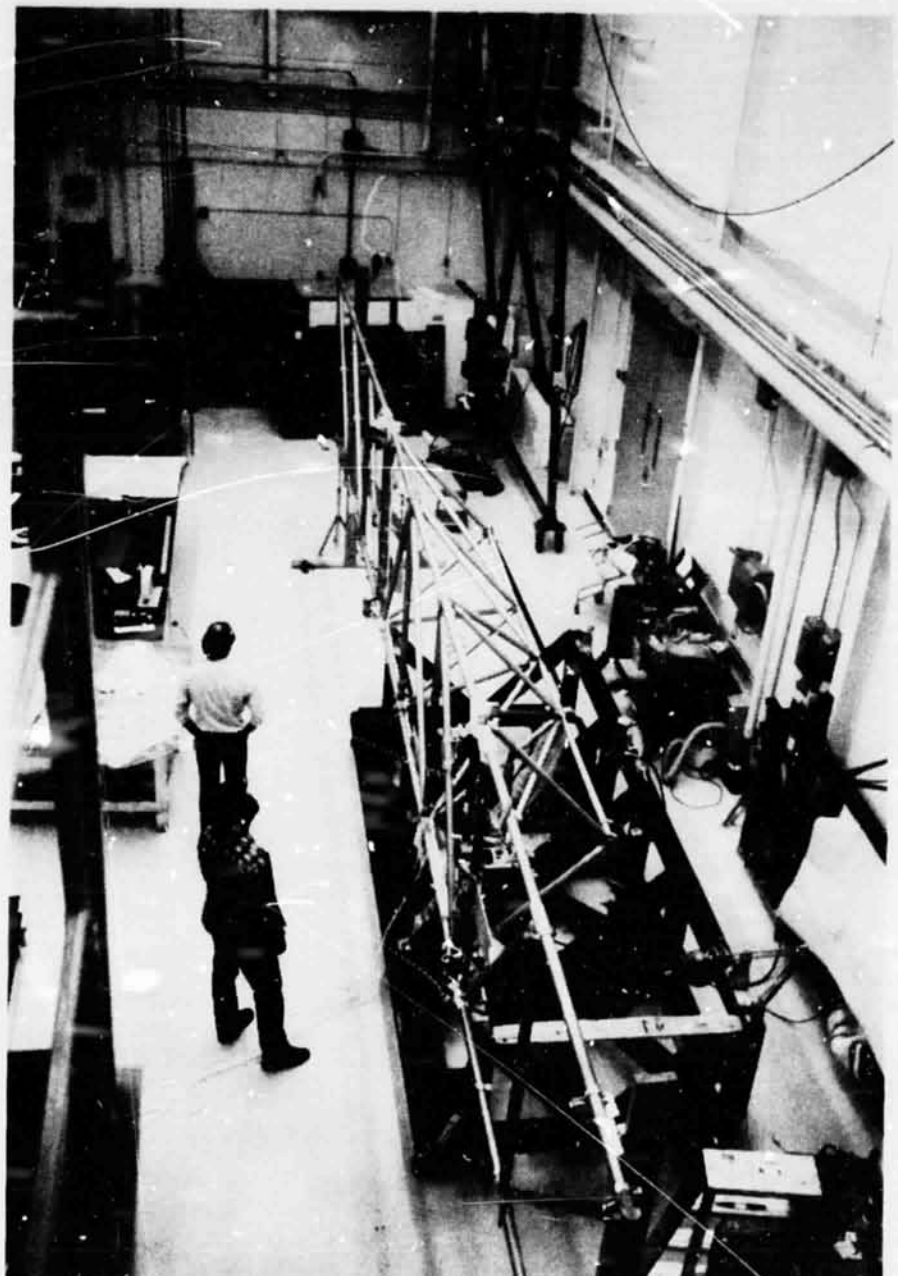

Figure 11. Antenna Truss in Deployed Position

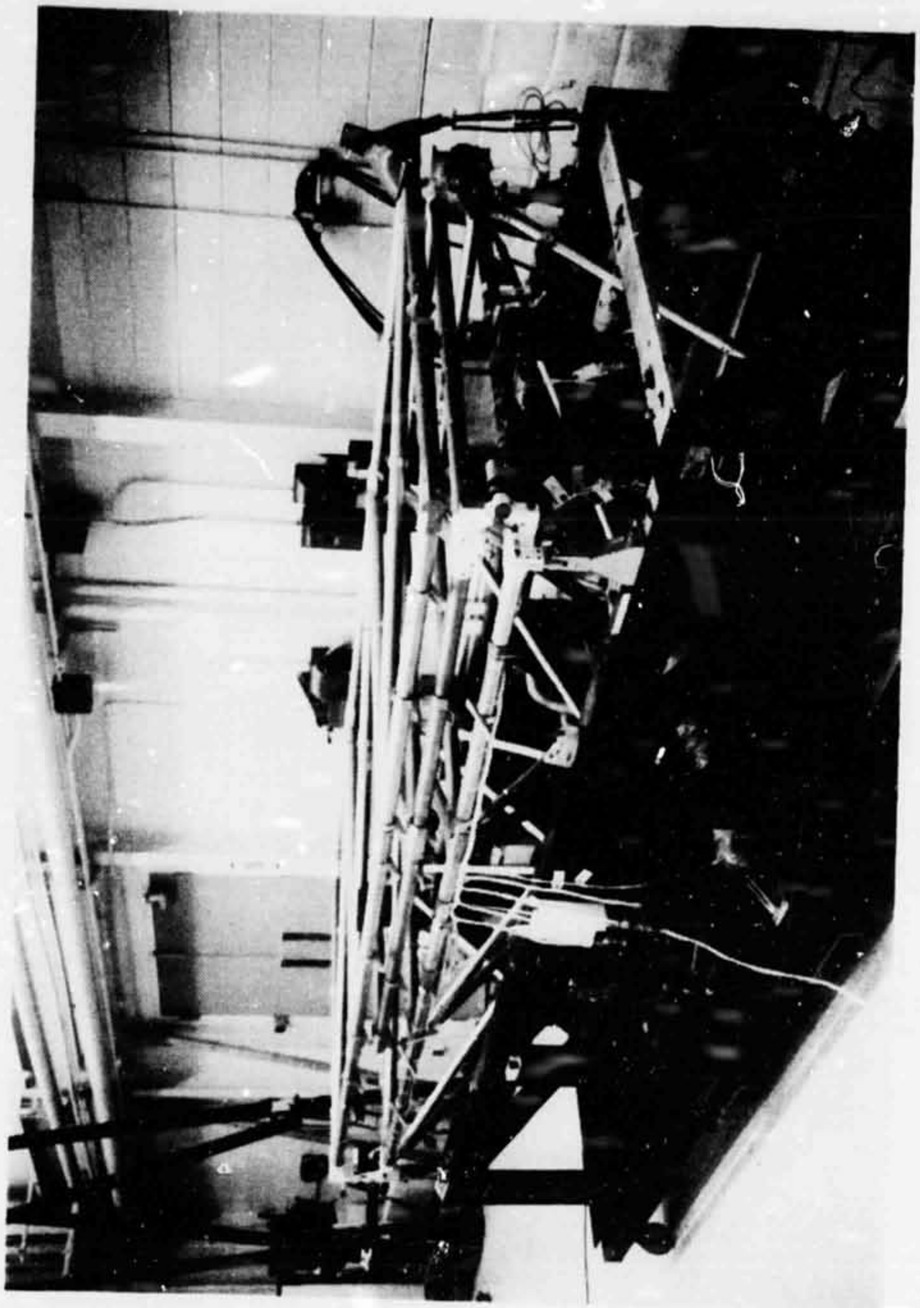

Figure 12. Antenna Truss in Stowed Position

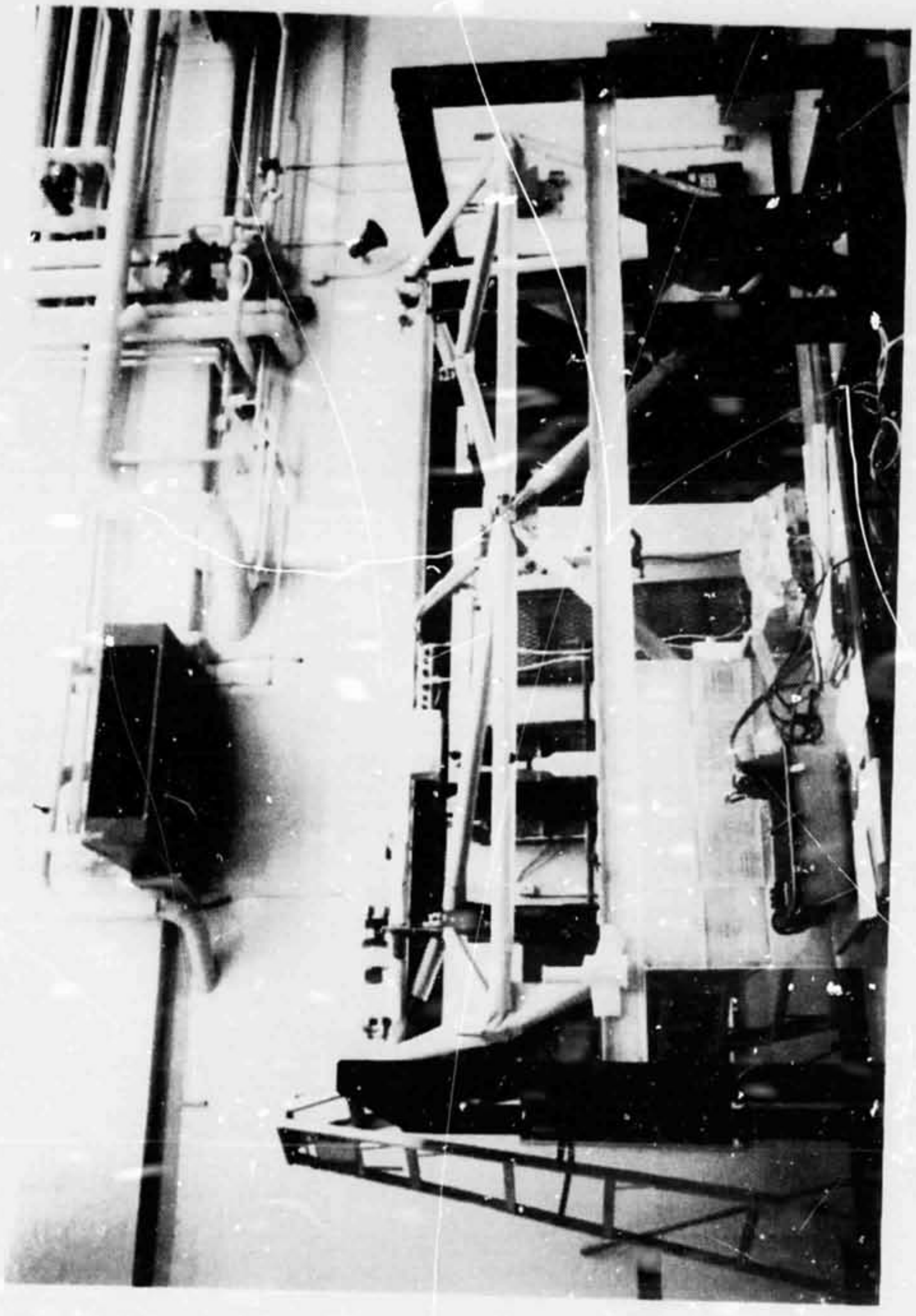

Figure 13. Pallet Truss

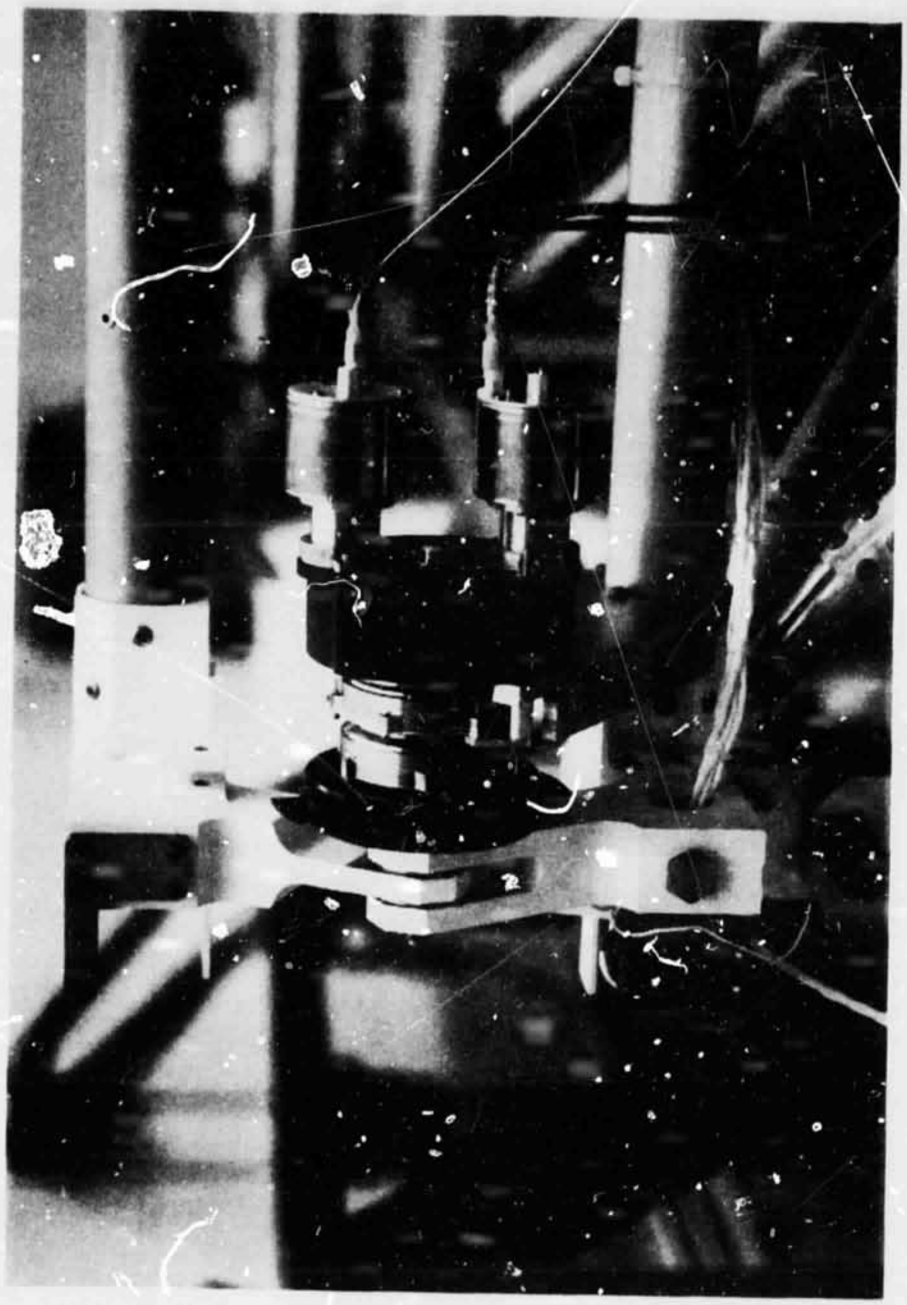

Figure 14. Typical Dual Drive Assembly Installation

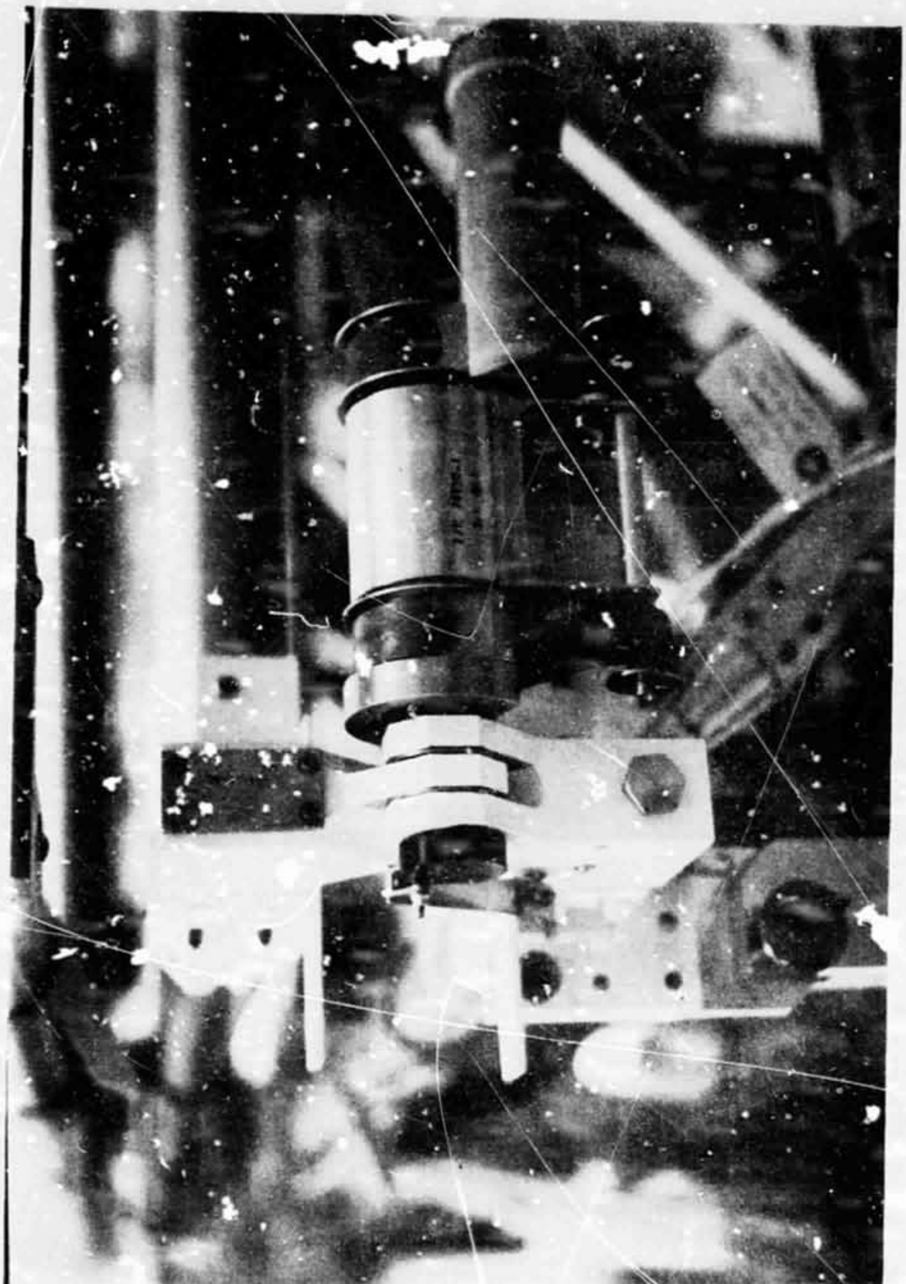

Figure 15. Typical Viscous Dampened Actuator Installation
(Shown in Preloaded Position Retained by Tooling Pin)

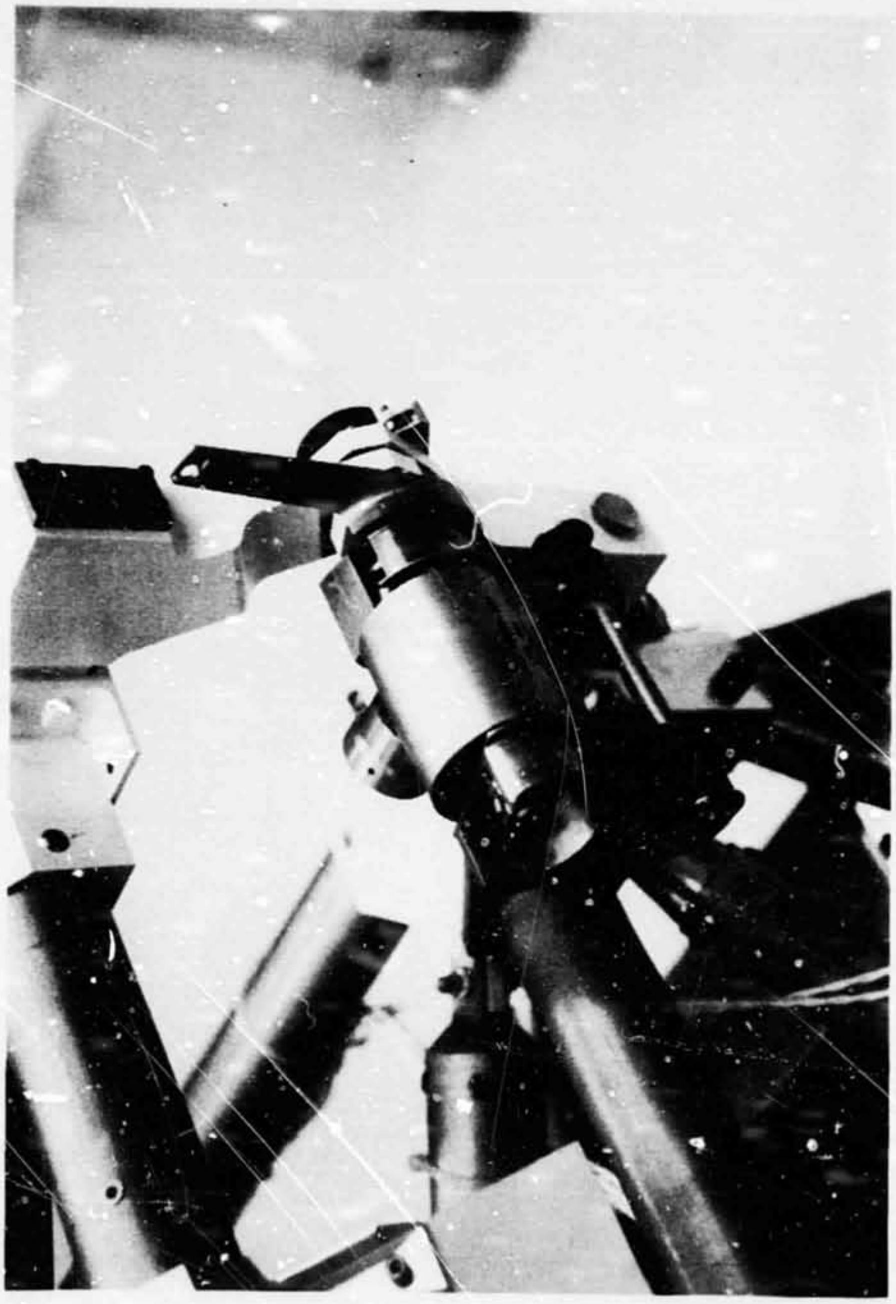

Figure 16. Viscous Dampened Actuator in Unloaded Position

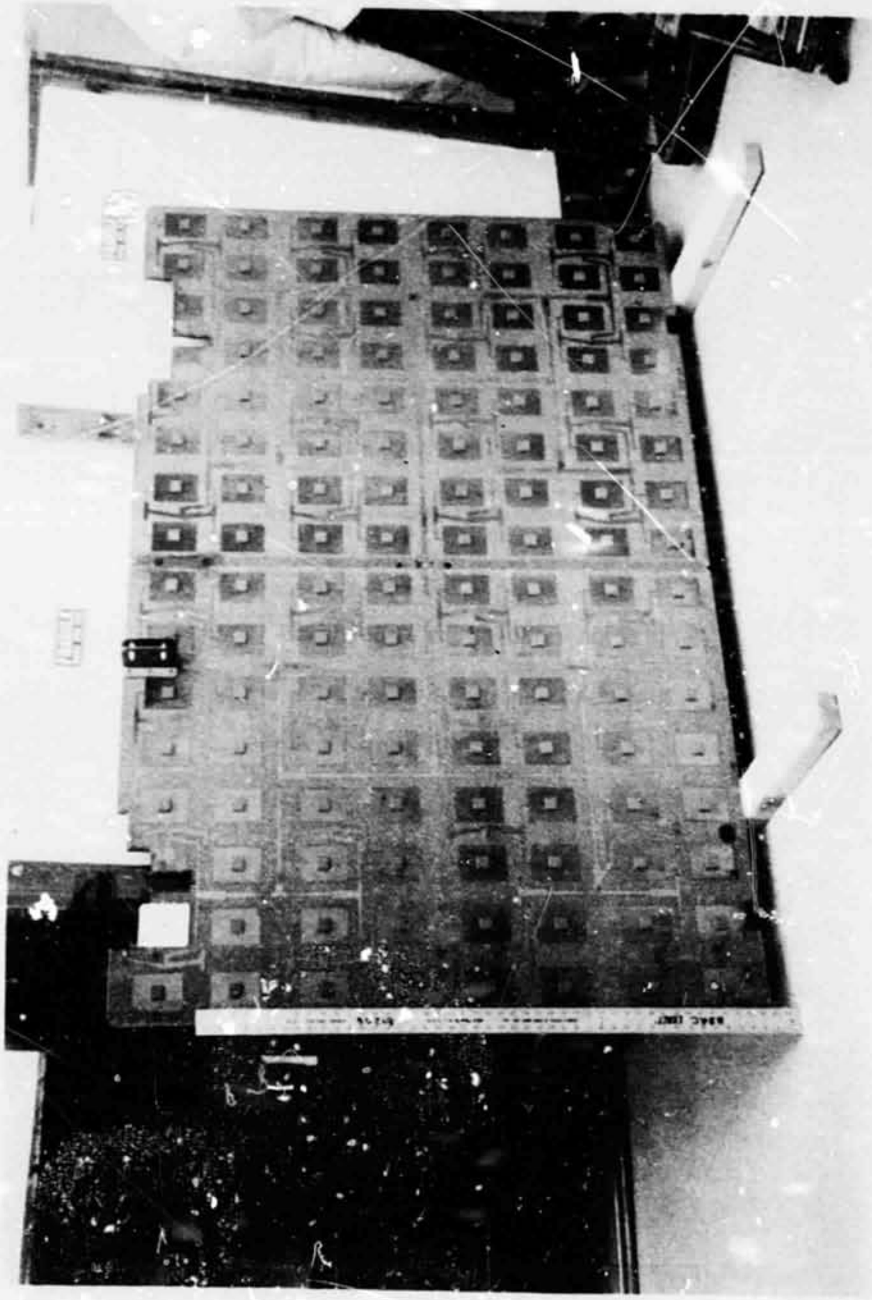

Figure 17. One of Eight RF Panels
(Ruler is 1.8 m (4-ft) long)